

**APPLICATION FOR
UNITED STATES LETTERS PATENT**

Be it known that we, Daniel M. Joffe, a citizen of United States, residing at
5 2732 Tammerack Lane, Huntsville, Alabama 35763; Richard L. Goodson, a citizen of
the United States, residing at 811 Jacqueline Drive, Huntsville, Alabama 35802; and
Curtis W. Dodd, a citizen of the United States, residing at 2803 Bentley Street,
Huntsville, Alabama 35801, have invented a new and useful "Method and Apparatus
for Reducing Flux Imbalance Signal Distortion in a Data Communications System."

BACKGROUND OF THE INVENTION

The present invention relates in general to communications systems, and is
more particularly directed to a simplex power feeding arrangement for furnishing
power from a central location to a remote location in a high-speed data
15 communications system.

This invention is directed towards the reduction of distortion in the signal
transfer from the central location to the remote location that may be caused by a
flux imbalance in the coupling transformers. This flux imbalance can cause a
reduction of the data transmission rates in high-speed communication systems.

20 Simplex power feeding arrangements, by their nature, cause very little
additional net DC flux density in a transformer. Typically, only an imbalance in the
ampere-turns product of each half of the line-side transformer windings causes an

undesirable additional DC flux density sometimes referred to as a flux imbalance. However, as transformers become smaller and data signal constellations have an increasing number of points, even a slight flux imbalance may cause significant and undesirable distortion in transmission signals. This distortion produces the most negative effect in echo-cancelled systems, where the local transmitter signal must be precisely cancelled to allow error-free reception of the remote signal. Distortion-free coupling of the local signal makes cancellation a relatively simple linear process, as compared to a complex non-linear process that might otherwise be required. Hence, there is a need for a way to counteract the imbalance in the transformer and thereby remove or reduce the distortion or non-linearity.

The problem of distortion caused by the flux imbalance may be solved if there is a way to counteract the magnetomotive force that produces the imbalance. Such a solution could achieve near maximum linearity while maintaining minimum size components.

In order to understand the benefits of a simplex powering apparatus and the flux imbalance problem it is useful to review a data communication system 100 shown in Fig. 1 with a simplex powering arrangement. The data communication system 100 utilizes a line powering supply 105 that may be located at a central location 96 of the communication system 100. This line powering supply 105 transfers power via communication lines 108, 109 to a power supply 106 at a remote location 98. The communication lines 108, 109 are typically twisted pair lines. The power supply 106 at the remote location 98 provides power to remote

data communications equipment, such as transceivers 110 and 112, or other data communications devices.

Although variations in the electrical characteristics of each coupling transformer 121, 122, 123, 124 or lines 108, 109 connecting the central location 96 to the remote location 98 are small, slight variations may cause a net DC flux density. This net DC flux density produces distortion in data communication system 100 having small transformers 121, 122, 123, 124. Modulation methods with a large number of constellation points may be affected to a greater extent by the distortion caused by the net DC flux density imbalance. In echo-cancelled systems with a large number of constellation points, the need for linearity is greatest. A highly linear system affords a relatively easy linear cancellation of the near-end signal, as opposed to a relatively difficult non-linear cancellation. Although a larger transformer may reduce the distortion problem, continual market pressure exists to make electronic communication devices smaller while increasing the data rate and therefore the need for constellations with a large number of points. Hence, there is a need for a method of removing the flux imbalance and allowing for the use of smaller sized magnetic devices such as transformers while maintaining or improving performance caused by the distortion due to flux imbalance.

SUMMARY OF THE INVENTION

One object of the present invention is to reduce the DC flux density in the magnetics of a transformer in a simplex power feeding arrangement such that the

net DC flux density approaches zero without adding significant complexity or size to coupling transformers of transceivers used in a communication system.

A further object is to provide a reduction in the DC flux imbalance that is adaptable to variations in transformer and line characteristics.

5 Yet another object of the present invention is to minimize the flux imbalance that may be generated as a consequence of non-idealities within the electrical circuits of the transmitter, such as by an offset voltage in an output amplifier.

10 An apparatus in a transceiver meeting the above and other objects is comprised of a means for measuring signal quality combined with a DC current injection means. The signal quality measuring means is comprised of a sampler and signal quality calculator. In a first embodiment, the sampler monitors the output of an echo canceller during simplex transmission and the quality calculator determines the average magnitude of the output of the echo canceller and then
15 directs the DC injection means to add a flux cancellation signal to the transmit signal in accordance with a flux cancellation algorithm. The flux cancellation signal and transmit signal are digital values and are converted to an analog signal, via a D/A converter, before going to an output amplifier. The flux canceller algorithm increases or decreases the flux canceller signal to reduce the value of the average magnitude of the output of the echo canceller.

20 The apparatus may be modified to provide for cancellation of the imbalance during a full duplex data mode by using an error signal from a linear equalizer as an input to the distortion measuring means.

A method for minimizing the distortion due to flux imbalance comprises the steps of: measuring the quality of the signal; injecting a DC current in an equipment side winding of a coupling transformer; measuring the quality again; increasing the injected DC current if quality has improved else decreasing the injected DC current; and repeating the above steps thereby reducing the distortion caused by flux imbalance.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic drawing of conventional simplex power arrangement used in a high speed communications system.

Fig. 2 is a schematic diagram of a summing amplifier for furnishing a flux cancellation voltage in accordance with the present invention.

Fig. 3 is a schematic and block diagram of a first embodiment of an apparatus for flux cancellation in accordance with the present invention.

Fig. 4 is a flow chart illustrating a first flux cancellation algorithm in accordance with the present invention.

Fig. 5 is a schematic and block diagram of a second embodiment of an apparatus for flux cancellation in accordance with the present invention.

Fig. 6 is a flow chart illustrating a second flux cancellation algorithm in accordance with the present invention.

Fig. 7 is a flow chart illustrating a method for flux cancellation in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to a simplex power feeding arrangement shown in the high speed communication system **100** of Fig. 1, the signal distortion problem associated with a net DC flux density can be understood. Line power and communication signals are often transmitted over two pairs of wires **108, 109** in the communication system **100** with a simplex powering arrangement. A central transceiver **101** and central transceiver **102** at a central location are coupled to a remote transceiver **110** and remote transceiver **112** over the communication lines **108, 109**. A line powering supply **105** at the central location furnishes DC current to a remote power supply **106** at the remote location. The remote power supply **106** furnishes power to the remote transceiver **110** and remote transceiver **112**. The simplex powering arrangement has the advantage that the DC current furnished by the line powering supply **105** produces nearly equal and opposite flux densities in a first transformer **121** as illustrated in Fig. 1. Current **I1** from the line powering supply **105** splits into two components, **I2** and **I3**. If **I2** and **I3** are exactly equal and the number of turns in the **I2** half or top side of the first transformer **121** is the same as the number of turns in the **I3** half or bottom side of first transformer **121**, then no net DC flux density is produced in the first transformer **121**. As shown by the dots **107** on first transformer **121**, **I2** flows out of a non-dotted end, and **I3** flows out of a dotted end. The dot notation is a standard and well-known convention for showing opposite signs in ampere-turns, or magneto-motive force. To the extent that **I2** and **I3** do not exactly match, or that the number of turns in the first transformer **121**

winding halves (N2 and N3 as shown in Fig. 2) are not exactly equal, there will be a net DC flux density. For example, the currents I2 and I3 will not match if the resistance of the I2 path is not equal to the resistance seen by the I3 path. This net flux density can cause distortion problems for the communication system 100.

5 The net flux density, also referred to as an uncanceled flux density, caused by the ampere-turn imbalance can be compensated or essentially removed by generating a compensating flux density in accordance with the present invention. The compensating flux density would be equal and opposite to the DC flux density produced by currents I2 and I3. The end result of the combination of the
10 uncanceled flux density and the compensating flux density in accordance with the present invention is a DC flux density in first transformer 121 much closer to zero. Typically, when the DC flux density is essentially zero then distortion in first transformer 121 is minimized. Fig. 1 also shows that a return path for current I1 is provided through the third transformer 123, fourth transformer 124, second
15 communication line 109, and second transformer 122.

Fig. 2 illustrates details of the first transformer 121, the amplifier 208, and the connections for other components for providing the compensating flux density. This compensating flux density is used to offset or cancel the uncanceled flux densities due to imbalances in currents I2, I3, and the windings N2, N3, and N4.
20 By adding a flux canceller signal 202, which comprises a varying voltage signal, to the summer amplifier 208 there is provided an additional degree of freedom to

assure that the net DC flux in the transformer 121 is zero as expressed by the equation:

$$I2 \cdot N2 - I3 \cdot N3 + I4 \cdot N4 = 0$$

In the ideal case, $I2 \cdot N2$ and $I3 \cdot N3$ are equal and there is no need for a flux
5 canceller signal or the ampere-turns expression $I4 \cdot N4$ of the equation. The line
side transformer windings $N2$ and $N3$ are on the line side of the transformer 121
and the equipment side winding $N4$ is on the transmitter side of the transformer
121. The currents $I2$ and $I3$ are typically DC currents but may contain small
variations with time as conditions change, such as a change in line characteristics
10 due to temperature change. In the above equation, the flux canceller signal is used
to cancel whatever uncanceled flux remains in order to minimize the transformer
distortion due to flux imbalance.

Now that a concept for a method and apparatus has been disclosed for
minimizing flux density and thereby minimizing distortion, details of a method and
15 a preferred embodiment will be given. Further, an apparatus for measuring
distortion and selecting a value for the flux canceller signal is also described.

Fig. 3 is a schematic and block diagram of the transceiver and transformer
sections of a typical full-duplex echo cancelled data transmission system 100 (Fig.
1). The transceiver may also be used in a simplex mode, such as during a training
20 mode. The transceiver includes a flux generator circuit formed by the combination
of a signal summer 302, a D/A converter 304, a filter 306, and amplifier 206. A
digital transmit signal 301 enters a summer 302. The summer 302 adds the digital

transmit signal 301 with a flux cancellation signal 303 to form a digital transformer signal 305. The digital transformer signal 305 is converted by digital to analog converter 304 and analog filter 306 to an analog transformer input signal 307. The analog transformer input signal 307 is then processed through amplifier 206 to form amplified transformer signal 309. The amplified transformer signal 309 is then sent to the equipment-side winding N4 in the transformer 121. The winding N4 in the transformer 121 converts the amplified transformer signal 309 into a transmitter signal, which includes a cancellation flux. The cancellation flux offsets the flux imbalance in the transformer to reduce or eliminate the flux imbalance. The use of a transformer winding to create flux is well known in the prior art.

The amplified transformer signal 309 is also sent to a combination echo canceller 308, which includes an analog echo canceller 310 followed by an analog to digital converter 312 and digital echo canceller 314. The combination echo canceller 308 is provided to cancel the near-end signal so that only the far-end signal and whatever nonlinear portion of the near-end signal remain. When the data transmission system 100 is operating in the simplex mode, the far-end signal is non-existent or zero. The combination echo canceller 308 is well known and understood by those skilled in the art of telecommunications and thus, no further comments will be given on this aspect of the invention.

Typical echo cancellers 310, 314 function as linear cancellers. These typical cancellers pass do not cancel non-linear echo components, such as those generated in transformer non-linearities such as flux imbalances. Thus, the flux imbalance

detection signals are not removed from the transformer signal. Therefore, the echo cancellers generate a detected quality signal that includes indications of the flux imbalance in the transformer. These uncanceled signals represent a distortion in the telecommunication system. Accordingly, the echo canceller acts as a distortion
5 measuring circuit.

The output of the digital echo canceller 314 minus any far-end signal represents a canceller error signal 315. This canceller error signal 315 is a measure of system distortion or quality. A relatively large magnitude for the echo canceller error signal 315 is an indication of poor quality and distortion. The echo canceller error signal 315 may be used in a feedback path to adjust the flux canceller signal 303 and thereby improve signal quality by driving distortion to a minimum.
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The improvement of the signal quality may be accomplished by using the canceller error signal 315 of the combination echo canceller 308 as a detected quality signal, and monitoring it with a flux controller 320. The flux controller 320 uses the detected quality signal to furnish a flux canceller signal 303 to the summer 302. The flux canceller signal 303 is the source for injecting a flux-canceling DC current into equipment-side winding N4. The flux canceller signal 303 is generated in accordance with the programming of the flux controller 320.
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In the simplex mode, the transceiver 100 adjusts the flux canceller signal 303
20 when the local transmitter is active and the far-end signal is silent. When the far-end signal is silent, the detected quality signal is directly related to the undesired signal. One measure of the undesirable signal is determined by calculating the

average magnitude of the detected quality signal over a group of samples. Those skilled in the art will recognize that alternative measures of the undesirable signal, such as the RMS value of the detected quality signal, could be used without departing from the scope of the present invention. Any method for determining a
5 measure of the undesired signal may be used that is associated with the generation of the correcting flux. Upon determining a magnitude of the undesirable signal, then the flux canceller signal **303** is determined in accordance with an adjustment algorithm **400** as shown in Fig. 4.

Referring now to Fig. 4, a first step **410** is to initialize the flux canceller
10 signal. In the preferred embodiment, this initializing step **410** sets the canceller signal to zero. Next, the undesired signal is measured (step **420**) to provide a baseline value. The process continues by repeatedly changing and monitoring the flux canceller signal (step **425**) to minimize the error signal. This changing and monitoring step **425** may be performed by increasing (step **430**) the flux canceller
15 signal **303** (Fig. 3) to modify the distortion caused by the transformer. The system will then compare (step **440**) the increase-modified canceller error signal against the baseline value. If the increase in the flux canceller signal **303** reduces the undesired signal or canceller error signal **315**, the system will attempt another increase of the flux canceller signal **303** to obtain additional reductions in the error
20 signal **315**. However if the undesired signal becomes larger and the distortion has increased, and the system will decrease (step **450**) the flux canceller signal **303**. The system will then compare (step **450**) the decrease-modified canceller error

against the current baseline value. If a reduction of the undesired signal is obtained, the step 450 of decreasing the flux canceller signal is repeated. This process is repeated until there is no further decrease in the undesired signal. The algorithm 400 then returns to step 430 to attempt additional reductions in the undesired signal. In the flow chart, the increase step 430 moves the flux canceller signal 303 in a positive direction and the decrease step 450 moves the flux canceller signal 303 in a negative direction.

The magnitude of increases and decreases in the flux canceller signal 303 may be varied. Typically, a range of positive and negative values of the flux canceller signal 303 is required to accommodate a range of flux imbalances. The flux canceller signal 303 may be also adjusted during full duplex transmission when the far-end signal is present; however, a different measure of signal quality may be required. In both transmission modes (simplex or full duplex), a quality measure related the amount of undesired signal is required and the flux canceller signal 303 is adjusted in accordance with the detected quality signal to minimize the undesired signal.

The adjustment procedure is also used beneficially to compensate for offset voltages that might be present at the output of the driver amplifier 206 shown in Fig. 3. If such an offset voltage is present, the offset voltage would cause a non-zero DC flux density in the transformer even if the line side currents and turns ratios were perfectly balanced. The system of this invention will detect these errors and generate a corresponding signal correction for the system.

Fig. 5 is a block diagram of a transceiver 500 for full-duplex transfer of data in accordance with the present invention. Both input data 501 and output data 502 are handled by this transceiver 500. Input data 501 is sent from the central location to the remote location and a signal from the remote location results in
5 output data 502.

The input data 501 is supplied to the transmitter 510. The output of transmitter 510 is a digital transmit signal and is combined with the flux canceller signal from flux controller 320 by digital summer 512. The transceiver 500 then operates in a similar manner to the previously described embodiment for
10 transmitting the signal. The output of the summer summer 512 goes through a D/A converter 304 and a filter 306 to a line driver circuit 513. On the receiving end, the combination echo canceller 308 provides a signal to an equalizer 514. Summer 512, D/A converter 304, filter 306, and line driver circuit 513 function together as a flux generator. The equalizer 514 has an equalizer error signal used as the detected
15 quality signal that is equivalent to the canceller error signal minus the output data signal. The arrangement for generating this type of signal is well-known to those skilled the design of data communications transceivers. One technique for providing the detected quality signal is to apply the output of equalizer 514 to a decision device which generates the constellation point closest to the equalizer
20 output. The difference between the equalizer output and the decision device output is the detected quality signal. The detected quality signal is used a measure of quality and is provided as an input to the flux controller 320. An RMS value or

average magnitude of the detected quality signal over N samples may now used as the measure of quality. The lower the value of the average magnitude, Q_i , the smaller the value of the distortion.

A second algorithm utilizing the reduction in Q_i in accordance with the present invention is shown in Fig. 6. The flux canceller signal is initialized at step 610 and, in the preferred embodiment, is set to zero. At step 620, the signal quality is determined and saved as Q_1 . The flux canceller signal is then incremented (step 630) and a new measure of quality is made (step 640) and saved as Q_2 . The two measures, Q_1 and Q_2 , are then compared (step 650) and if the quality is improved then Q_1 is set (step 660) to be equal to Q_2 and steps 630 through 650 are repeated. If the comparison step 650 shows that quality has not improved, then the flux canceller signal is decremented (step 670), and a quality measurement (step 680) is made. The two measures, Q_1 and Q_2 , are then compared again (step 685) and if the quality is improved then the Q_1 is set at step 690 to be equal to Q_2 and steps 670 through 685 are repeated. If no improvement is made, then the program returns to step 630 to begin the correction process again.

Figs. 4 and 6 each describe flux canceller algorithms for generating the flux canceller signal in accordance with the present invention. Those skilled in the art would appreciate that any measure of quality could be used to provide the flux canceller signal. Fig. 7 describes the overall method of the present invention. The flux canceller signal is set (step 710) to an initial value, typically zero. In step 720 a quality measurement is made and the flux canceller signal is adjusted (step 730).

The flux canceller signal is then measured and readjusted (step 740) in response to the changes in quality in accordance to a flux canceller algorithm.

Although there have been described particular embodiments of the present invention of an apparatus and method for reducing flux imbalance distortion in a high speed communications system, it is not intended that such embodiments be
5 construed as limitations upon the scope of the invention except as set forth in the following claims.

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